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Metal Melting Efficiency Project

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1.0 Introduction

1.1 Report Overview

This report is the result of a California Energy Commission PIER Research Contract to reduce energy usage in the metal casting industry. The focus is on the major electrical energy usage area of metal melting. The California Cast Metals Association (CCMA) and its subcontractor, Technikon LLC, have prepared this report to supply timely information that foundries, die casters, and smelters could use to reduce their electrical usage in the short term as well as for longer term planning.

This report is divided into three main sections:

Section 2: Foundry Energy Survey Results. Gives an overview of the responses of a statewide survey sent out to determine general information of the industry. See the Appendix section for graphical details.

Section 3: Energy Usage and Cost Savings Strategies. Technical recommendations on metal melting energy usage and areas of potential reductions.

Section 4: Energy Providers and Energy Management: Recommendations on interfacing with Energy suppliers on rate structures and using energy management tools to reduce usage.

1.2 Foundry Energy Overview

The Metal Casting Industry is a major consumer of energy for the production of a myriad of castings, which are used in 90% of all manufactured goods. California is ninth in the United States in tonnage of castings produced with more than 20,000 people employed in the industry.

According to 1999 Department of Energy (DOE) "Energy and Environmental Profile of the U.S. Metal casting Industry Report", metal casting is among the most energy intensive industries in the United States. The distribution of that energy usage (gray and ductile iron foundries) from that report is shown below in Table 1. The energy mix reported is shown below in Table 2.

Table 1. U.S. Distribution of Energy Usage in Ferrous Foundries

Process Step	Percentage
Melting	55%
Mold Making	12%
Core Making	8%
Casting Cleaning	7%
Heat Treat	6%
Other, painting, sand reclaim, etc.	12%
Total	100%

Table 2. Types of Energy used in U.S. Ferrous Foundries

Fuel	Percentage Use
Electricity	58.5%
Natural Gas	21.4%
Coke and coke breeze	18.9%
LPG	0.6%
Coal	0.6%
Total	100%

The purpose of this report is to help California foundries reduce energy usage in the short term, and to develop guidance for longer term planning. Since metal-melting represents 55% of the total energy used in the production of castings, the focus of this study is on that particular area of foundry operations.

2.0 California Foundry Energy Survey Results

2.1 Survey profile of foundries that supplied information used in this report:

Survey forms were sent out to more than 200 foundries, die casters and smelters operating in California. Responses were received from 69 companies, some with multiple facilities. The data presented in the following tables represent a summation of those responses. The major foundry operations represented in these tables produce nearly 400,000 tons of cast products per year. The Appendix contains detailed graphs and spreadsheets that these tables were developed from.

Table 3. Type and Percentage of Metal Melted

Metal Family	Specific Metal	% of Tonnage
	Ductile Iron	31%
Ferrous operations	Gray Iron	26%
	Steel	7%
	Aluminum	18%
Non-Ferrous operations	Brass	7%
	Zinc	6%
	Other	5%

Table 4. Foundry Molding Processes Utilized

Foundry Molding Process	Percentage
Greensand Molding - Manual	32%
Greensand Molding - Automatic	11%
Ingots	27%
Centrifugal Casting	10%
No-Bake Molding	8%
Shell Molding	3%
Permanent Molds	2%
Die Casting	1%
Other	6%

Table 5. Foundry Coremaking Process Utilized

Foundry Coremaking Process	Percentage
Shell Core and Molds	54%
No-Bake Cores and Molds	37%
Cold Box Cores	6%
Hot Box Cores	2%
Other	1%

2.2 Melting Equipment Profile:

The following tables reflect the type of furnaces being utilized by the foundries, die casters and smelters. The larger Ferrous and Non-Ferrous operations have selected furnace types that are not electrical. The two largest ferrous foundries use cupola melting and they account for 41% of the total tonnage in the survey. The larger non-ferrous foundries and smelters utilize gas furnaces.

Table 6. Ferrous Foundry Melting Furnace Profile

Metal Family	Type of Furnace	% of Tonnage
	Cupola	70%
Ferrous Foundries	Coreless Induction	21%
	Arc	9%
	Channel Induction	<1%

Table 7. Non-Ferrous Foundry Melting Furnace Profile

Metal Family	Type of Furnace	% of Tonnage
	Induction Coreless	21%
Non-Ferrous Foundries	Gas Reverb or Crucible	76%
	Electric Resistance	3%

2.3 Energy Providers and Rate Structures Profile:

Information was requested on the survey on Energy Providers and Energy Usage. The following tables contain a summary of the information obtained.

Table 8. Energy Providers from survey

ENERGY PROVIDER	% OF FOUNDRIES IN SURVEY
Burbank PSD	4%
City of Lodi	3%
Pacific Gas and Electric	18%
LA Department of Water and Power	4%
San Diego Gas and Electric	4%
Southern California Edison	67%

Table 9. Rate Structure from survey

RATE STRUCTURE	% OF FOUNDRIES IN SURVEY
General Schedule	12%
Interruptible	33%
Real-Time Pricing	22%
Time-of-Use	33%

Definition of Rate Structures:

- ***General Schedule***: This rate structure is for low demand and low energy customers where the customer agrees not to exceed a certain number of kW during a specified period of time and to use not less than a specified amount of energy per year in exchange for lower rates. If the customer demand (kW) exceeds the demand limit then the rate structure is changed by the energy provider to a more costly rate structure. There are many variations of this rate structure that may include time-of-use or interruptible rate provisions.
- ***Interruptible:*** This rate structure generally provides lower prices in exchange for customer agreement to comply with possible calls by the energy provider to interrupt service.
- ***Real-Time Pricing:*** As the name implies the customer pays current market rates for energy from moment to moment throughout the day. This rate structure utilizes a special meter that allows energy billing based on market prices as they very throughout the day.
- **Time-of-Use (TOU):** This rate structure has demand and energy charges that vary by time of use and season. With the TOU rate structure, energy and demand charges are higher during peak and super-peak times of day to encourage operations during off-peak hours to reduce demand on the electrical grid.

Table 10. Electrical Cost and Usage Information of electric melting foundries

ENERGY	AVERAGE OF SURVEY
Average Cost per Ton	$74
Average kWh per Ton	1170
Average Cost Per kWh	$.085

2.4 What Foundries are doing, or are planning to do, to manage the Energy Crisis:

The following questions were asked on the survey to determine the effects of increasing energy costs were having on foundry operations. The comments to some of the general questions asked in the survey are both insightful and instructive:

- ***Have you changed your operation because of increased energy costs?*** **54% said YES.**

  Comments:
  - Significant cost increases have not been experienced yet.
  - Have removed all incandescent bulbs and replaced them with energy efficient bulbs.
  - Changed to off-peak operating hours.
  - Shut down electric furnace and activated gas furnace.
  - Reduced non-essential electrical loads and conduct all melting operations before noon (high peak period).
  - Considering changes in scheduling to take advantage of off-peak hours.
  - Melt nights. Lowered maximum kW to drop demand charge.

- ***Have you changed worker shifts to avoid potential interruptions or higher costs*?** **48% said YES.**

  Comments:
  - Start shifts early. Shifts are complete by 3:30 p.m.
  - Melt early in the morning.
  - No, savings would be offset by labor costs.
  - Employees do not want to work the changed shifts.

- ***Which is a bigger concern: cost of power or interruption of power?*** **Equal split between cost and interruptions.**

  Comments:
  - Facility is exempt from rolling blackouts.
  - Concerned about damage to ladles, crucibles and safety.
  - Interruptions. Customers out of state do not understand.
  - Safety.

- We are near two schools so they do not interrupt our power.

- ***Have you implemented energy savings changes because of the energy crisis?*** **74% indicated they had made changes.**

  Comments:
  - Reduced non-essential electrical loads.
  - Have conducted employee training regarding efficient use of energy.
  - Turn off air compressor more often.
  - Turn off equipment whenever possible. Trying to save 40% of lighting costs.
  - Changing of starting times of melt department to avoid peak demand period
  - Installation of energy efficient equipment, new compressors, motors, variable speed drives
  - Install generators for demand control

- ***What energy savings equipment, methods or concepts are you considering?***

  Comments:
  - None at the moment. Electrical resistance furnaces were installed in the late eighties and early nineties to save energy costs.
  - The facility has two electric furnaces that have not been used in ten years because electricity triples the melting costs.
  - Lighting, point of use air compressors, energy efficient motors and change of shifts.
  - Considering the purchase of a new induction furnace with a lid to conserve heat during the melting process.
  - We are considering capturing the exhaust heat from our reverb furnace to preheat our aging ovens.
  - Install on-site power generation.
  - New lighting, shift changes and distributed generation.
  - Change shift hours during summer months to avoid power interruptions and demand changes.
  - Demand control, lighting retrofits, heat recovery, standby and distributed generation.
  - We have hired an outside company to analyze (operations) and give recommendations.
  - Variable speed drives for die casting machines and air compressor; new energy efficient furnaces; wind generator; solar.
  - We are installing a generator to meet our on-peak and power outage period uses.

- ***Are you Capturing Heat from melting furnaces?*** **100% indicated they were not.**

- ***What % of operating costs are energy cost*** **Average of responses was 25%.**

- ***Does your operation have Energy Monitoring on Melting operations?*** **28% had some monitoring in place.**

3.0 Energy Usage and Cost Savings Strategies

3.1 Foundry Equipment Utilized in Melting Operations:

The basic metal melting processes all require application of heat to raise the charge materials to their respective melting points. The major melting processes available for foundries, smelters and die casters include:

- Electric Furnaces
  -Coreless Induction furnaces
  -Channel Induction furnaces
  -Arc furnaces
  -Resistance heated - reverberatory & crucible

- Gas Furnaces
  -Reverberatory
  -Crucible

- Cupola Furnaces (coke fired)

In Ferrous Operations: The Cupola dominates the production tonnage based on its use at just four (4) foundries, 70% of ferrous foundry tonnage. Foundries utilizing Cupola Furnaces are few in number but are high production shops. Induction Melting is used for melting in 21% of the tonnage. Arc furnaces are used by two (2) Steel Foundries, and represent 9% of the ferrous foundry production.

In Non-Ferrous Operations: Gas melting furnaces are used to melt 86% of the tonnage and Induction and Electrical Resistance for 24% of the tonnage.

The following sections will focus on Electric melting furnaces, but will review choices of gas furnaces that could be an alternative to electric melting. A short section is dedicated to Cupolas energy savings suggestions, but this report is not intended to get into all the details on cupola operation.

3.2 Induction Melting Furnaces:

According to a 1996 survey of iron and steel foundries by the EPA's Office of Air Quality Planning and Standards, 95% of induction melting furnaces have capacities less than 10 tons per hour. They are used in both Ferrous and Non-Ferrous applications, but are more frequently used in iron and ductile iron foundries. The major types of induction furnaces use either coreless or channel induction technology. The coreless furnace design is primarily used for melting and the channel furnaces are primarily used as holding furnaces.

An Induction furnace consists of a refractory structure surrounded by a water-cooled copper coil through which alternating current is passed (see Figure 1). This current creates a magnetic field that induces a current on the surface of the metal. The heat generated by this current is conducted into the metal, causing melting. Two variables can affect the degree of heating achieved in an induction furnace: the magnetic fields rate of variation (frequency of the power) and its intensity (power input). 75% of the energy delivered is used in melting and in increasing the temperature of the metal in the furnaces. The remaining energy losses are: a) heat carried away through the refractory lining and into water-cooled coils; and b) heat radiation losses through the lid opening.

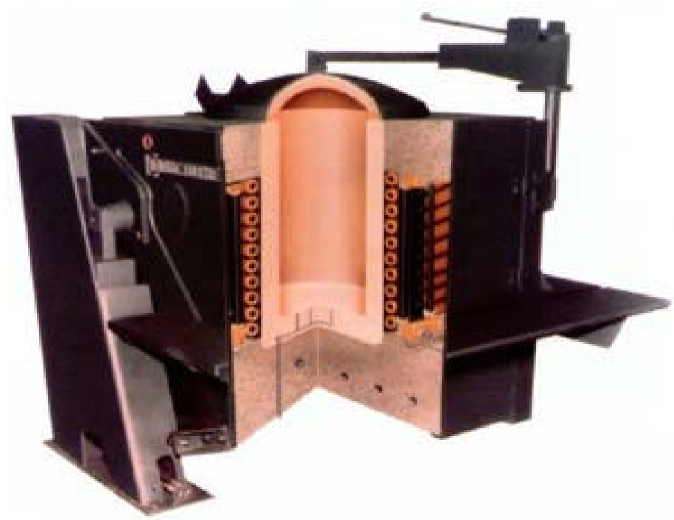


Figure 1: Cut Away of typical Coreless Induction Furnace (Inductotherm)

The design and efficiency of induction furnaces have improved over the past 30 years. Figure 2 shows typical information on energy efficiency of induction furnaces by decade built (derived from Inductotherm Corporation data).

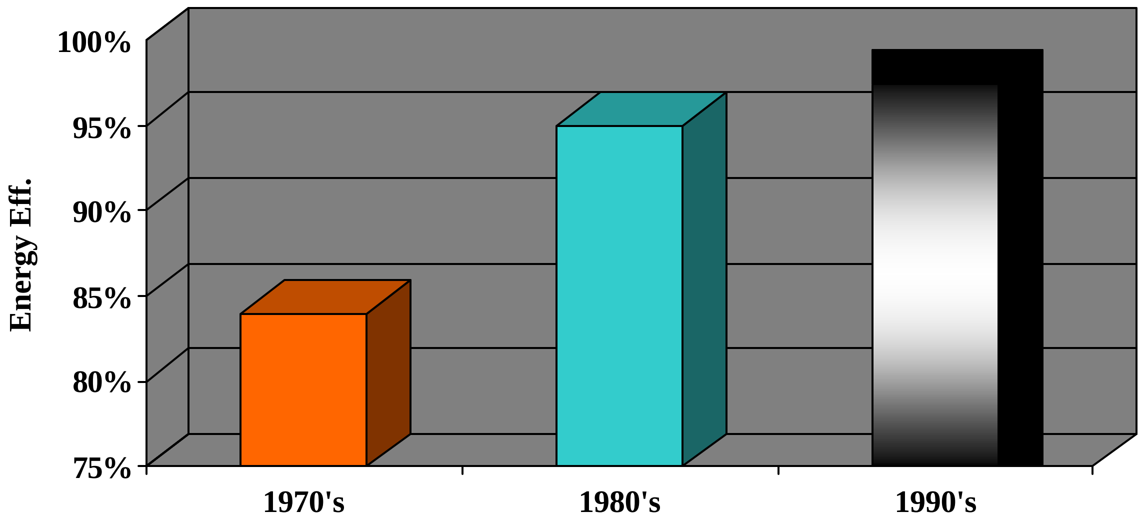


Figure 2: Power Supply Energy Efficiency Improvements

The older 60 Hz power supplies can easily be upgraded to new solid-state induction power supplies. This can usually be done without replacing the older furnace coils or shunts. A modern medium frequency solid state power supply can melt about 20% more metal per kilowatt and do it faster since full power can be supplied during the entire melting cycle.

Two methods are used for operating a coreless induction furnace: a) Continuous Batch method (tap and back charge); and b) Batch Melting.

A coreless induction furnace operating on a Continuous Batch method cycle begins with a full furnace at the proper tap temperature. As ladles are removed, an equivalent size back charge is dropped into the furnace. This new charge melts and the bath is reheated to the desired temperature. This process continues during the day, as production requires. It takes about 430 kWh of energy to heat one ton of iron from ambient to 2800F. With the typical energy losses though the lining and lid, the total energy consumption is about 500 to 550 kWh. The energy to hold the metal at temperature is about 20% to 30% of the energy required for melting.

In conventional coreless induction iron melting, the operational cycle consists of an on-power period for melting and superheating followed by an off-power period for slagging, pouring, and charging. Total time for the on and off power periods is the melt cycle time. Since melting only occurs during the on-power part of the cycle, it only follows that optimization of the “power-on” time will improve the energy efficiency of the operation.

The Batch method requires the furnace to be completely empty at the end of each melt cycle and restarts with a solid charge for the next cycle. Since the furnace is poured empty after each batch there is no molten bath. The energy efficiency is improved because the magnetic coupling with a molten bath is around 80% but the coupling is about 95% with a solid charge. This allows induction systems with a constant power draw to have an overall furnace electrical efficiency of 88%; with batch melting, versus the 80% for a continuous batch melt furnace.

A limitation to Batch Melting is that the furnace size is limited by being required to empty the furnace quickly. To solve this logistic problem a holding furnace can be added. Another solution to is to gang two furnaces together with a common dual output power supply. This allows batch melting in one furnace and pouring from the other furnace, which has only holding power.

3.2.2 Induction Furnace Energy Saving Concepts:

To reduce the energy used in melting with coreless induction furnaces the following operational methods are suggested to reduce thermal losses:

a. Minimize the time the furnace bath is uncovered, e.g., (a 12 ton furnace will lose 14 kWh for every minute the furnace lid is open).
b. Reduce Slag generation. Not only does it require about 410 kWh per ton to melt slag it also requires opening the lid for removal. Suggestions to reduce slag include: a) improving quality of scrap purchased; b) cleaning the sand from returns prior to charging; and c) stabilize tap temperature (lower temperatures produce less slag).
c. When taking bath temperature or introducing additives, minimize the opening of the lid (see Figure 3) or add hole through the lid for probe.
d. Purchase properly sized scrap, which melts faster because it is more densely packed.
e. Reduce power input while tapping and charging furnace.

Figure 3: Minimize Opening for Using Temperature Probe

Scrap pre-heating is a simple way to reduce electrical demand in melting. The typical method is to use a vibrating scrap feeder that heats the scrap with natural gas burners (see Figure 4). In these systems, raising the temperature of one ton of scrap from ambient to 1000°F saves approximately 100 kWh of electricity, which is being offset, with 600,000 Btu's of natural gas. This amounts to about a 20% electrical energy savings in addition to a 20% melt rate increase.

Newer design pre-heater designs use insulated scrap buckets that are heated to 800°F with direct firing gas torches. A rotating table is used to fill, heat and transfer buckets to the furnace. These systems claim a 200 kWh reduction per ton of charge (April 2001 "Foundry Management and Technology").

Other methods of pre-heating scrap prior to charging involve the use of waste heat from other sources. Recent proposals have been made to use the exhaust gases from a natural gas generator to soak scrap in insulated chambers to temperatures approaching 1000°F.

An advantage of pre-heating is that although the cost of natural gas has to be considered in the cost of melting, there typically is a significant cost savings. In addition, safety benefits result from scrap pre-heating since most moisture and oils are removed prior to entering the furnace. The downside is another potentially regulated emission source has been added to the operation.

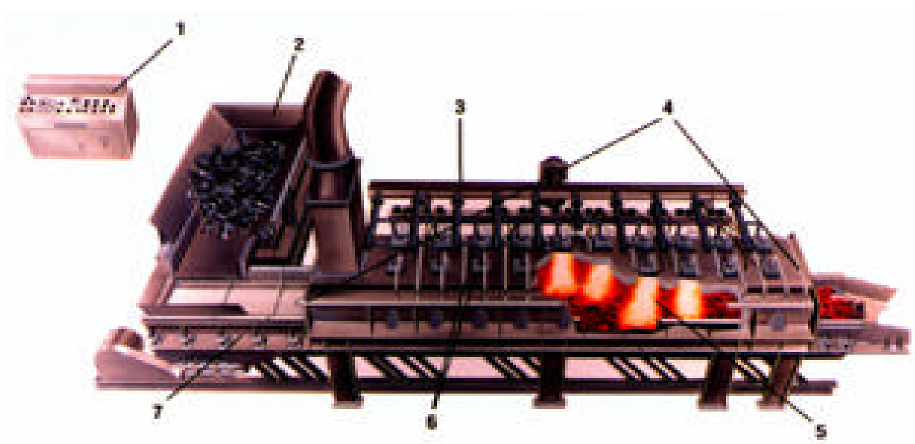


Figure 4: Scrap Pre-Heater (Inductotherm)

3.3 Channel Induction Furnaces:

Channel Induction furnaces are normally used as holding furnaces in conjunction with arc or cupola furnaces. They have found some application as a melting furnace, particularly for overnight melting to take advantage of lower rates. The basic design of the channel furnace involves the use of an induction coil that is external to the furnace. A loop of molten metal is drawn electromagnetically through a water-cooled coil surrounded with refractory (see Figure 5). The induction heating action occurs in the lower section of the furnace and transfers superheated metal to the body of the furnace. This inductor design can be either single or double loop. Inductor efficiencies are in the 95% range but radiation losses are significant for an overall furnace efficiency in the order of 75%.

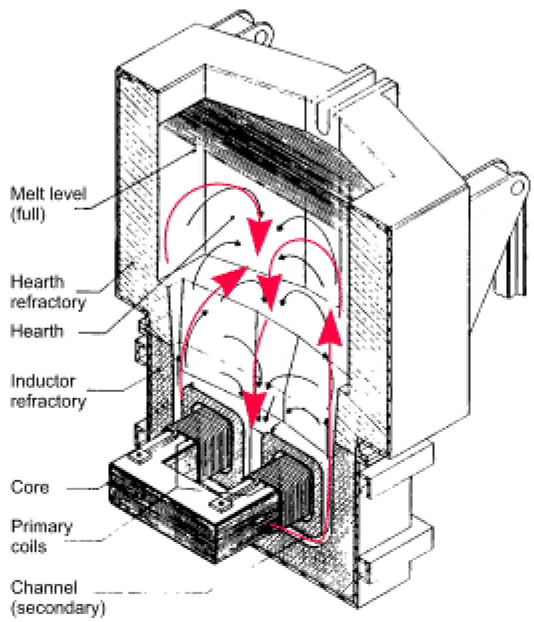


Figure 5: Double Loop Inductor Channel Furnace (Ajax)

When used as a holding furnace, the inductor must only compensate for radiation losses and inductor cooling losses (75 to 150 kWh per ton depending on throughput). For uses with cupolas, some superheating capacity is required. If used as a melting furnace, additional power input is required.

The major disadvantage of channel furnaces is they require continuous power. It is not unusual to keep metal molten in the furnace 12 to 18 months before relining of the furnace is required. Only foundries with nearly continuous casting operations can afford to operate these furnaces. Additionally, loss of power for an extended period requires dumping of the furnace and replacement of the inductors.

3.3.1 Channel Induction Furnace Energy Savings Concepts:

a) Like coreless induction furnaces, radiation losses through channel furnaces slagging doors and spouts are the major controllable energy saving areas. Minimization of slag getting into the furnace will save opening the doors or lid to remove slag. Excessive slag also accumulates in the throats of the inductors requiring superheating to melt the slag out.
b) Re-engineering of the internal refractory insulation can both decrease energy losses and also can increase the holding capacity of the furnace.

3.4 Electric Arc Furnaces

Electric Arc furnaces use two or three electrodes in creating an arc that generates the heat to melt metal in a batch mode. The 3-electrode design is the more common and is known as a direct arc furnace. Each electrode is connected to one lead of a three-phase power supply (see Figure 6). The metal is melted primarily by direct radiation from the arc and by the resistance of the metal between the arc paths. Energy usage in arc furnaces is between 500 and 600 kWh per ton of iron.

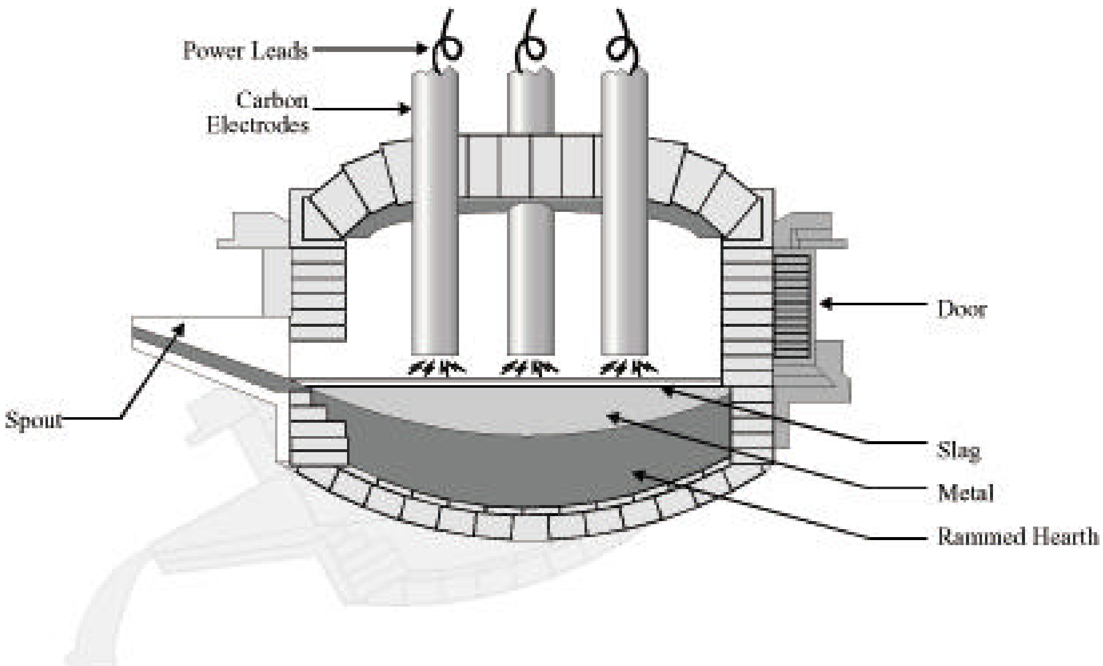


Figure 6: Arc Furnace

3.4.1 Arc Furnace Energy Saving Concepts:

a. The arc regulation system controls the distance of the electrode tip and the furnace charge. If improperly adjusted, long and inefficient melt cycle can occur.
b. Arc furnaces are sensitive to incoming variation in electrical power. This can affect the maintenance of the arc causing excessive electrode wear and productivity. Monitoring of incoming power voltage and frequency may be necessary.
c. Interruptions in melting cycles waste energy. Minimize the metal holding time in the furnace. Arc furnaces are most efficient operating as melters, not holding furnaces.
d. Arc furnaces are most efficient if the time between recharging is minimized. Radiation losses from the walls and roof occur when the furnace is empty and the heat has to be recovered during next melt cycle.
e. Adding supplemental oxygen/gas burners are reported to reduce power consumption by 34 to 58 kWh/ton and increase output up to 7%.

3.5 Aluminum Furnace:

Melting aluminum is an energy intensive process; it takes about the same amount of energy to raise one pound of aluminum to 1300°F as it does to raise one pound of iron to 2700°F. Of course, because of the density difference you can get three times as much castable metal from a pound of aluminum compared to iron. The most common furnaces for aluminum are reverberatory and crucible designs that can use multiple energy sources (electricity, natural gas, and propane or fuel oils).

The electric resistance heated reverberatory melting furnace is commonly used for aluminum melting (see Figure 7). These furnaces are constructed with a refractory lining in a steel shell. The furnace is heated by silicon carbide resistance elements mounted horizontally above the bath. Heat is transferred through indirect radiation from the refractory walls and roof. Energy losses are primarily through the shell and typical electric energy usage is 500 to 825 kWh per ton of aluminum.

The fossil fuel versions of reverberatory furnace are of the same basic design but they use burners in place of resistance elements to generate heat (see Figure 8). The electrically heated designs are about 35% more energy efficient because they do not have the lost of heat going up the stack that the fossil fuel systems do (which also results in increased air pollutants). Gas or oil fired basic furnaces use about 1500 to 3400 Btu per pound per hour (880 to 1990 kWh per ton), compared to 500 to 825 kWh per ton for electric heated. In addition, gas furnace increases metal losses due to oxidation; 5% to 8% metal loss for a gas furnaces as compared to 0.5% to 3% loss with electric furnaces.

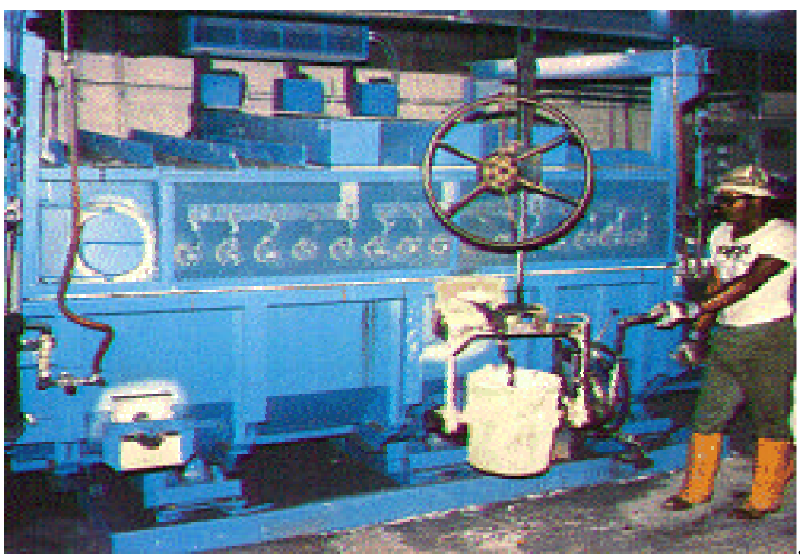


Figure 7: Electric Reverberatory Furnace (Schaefer)

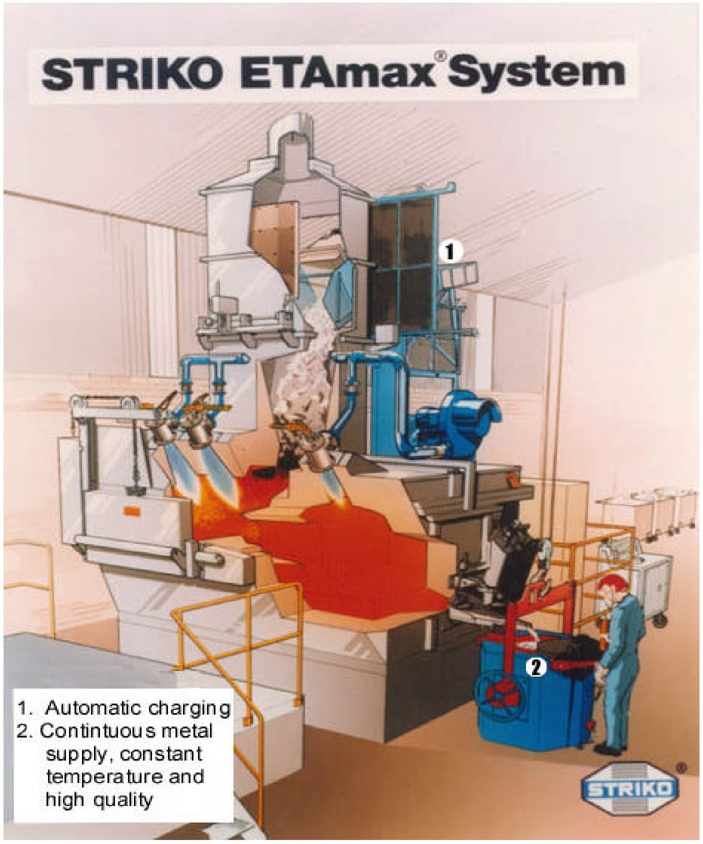


Figure 8: Gas Reverberatory Furnace with Pre-Heat Chamber (Striko Dynarad)

In crucible or pot furnaces, electric resistance heating elements are installed on the inside refractory wall of the furnace. These elements radiate heat to the crucible (generally manufactured of cast iron or silicon carbide), which in turn conducts heat into the metal contained in crucible (see Figure 9). Crucible furnaces are generally less efficient than other electric aluminum furnaces, but have the advantage of being able to be emptied and shutdown.

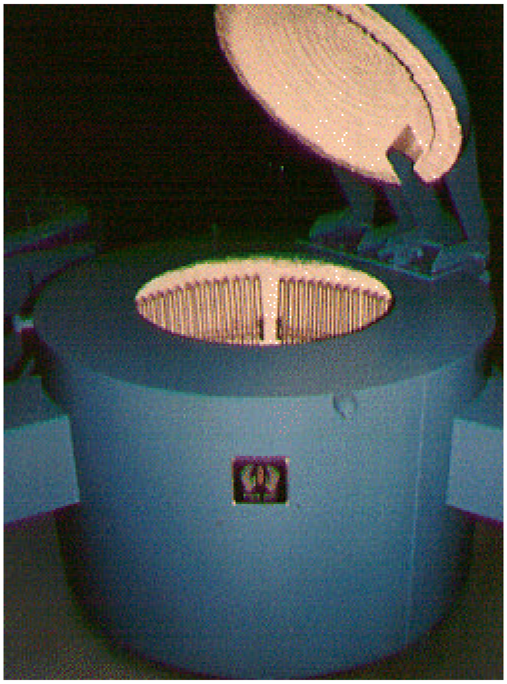


Figure 9: Electric Crucible Furnace (Schaefer)

Crucible furnaces are also designed for use as holding furnace as shown below. Multiple chambers are common, with a separate spout for filling and an open bath for metal removal (see Figure 10).

Figure 10: Electric holding furnace (Striko Dynarad)

Crucible furnaces are also available as gas fired units, but energy efficiency is low, in the range of 25 % to 28%, compared to 83% for electrically heated (see Figure 11).

Figure 11: Gas Crucible furnace (Thermtronix)

With today's increasing electrical cost, the choice of fossil fueled aluminum furnaces need to be balanced against pollution abatement cost when considering future melting capacity or as a replacement for crucible or reverberatory furnaces. Recent design innovations in fossil fuel reverberatory furnaces help capture the waste heat in the stack gasses and use them to pre-heat charge materials. This increases energy efficiency and reduces melt time. Recuperation of the waste heat can also be used to pre-heat combustion air. The combination of these technologies can reduce fuel usage to 1000 Btu per pound (580 kWh per ton) of aluminum. This still is not as efficient as the best operating electrical melt furnaces, but the typical gas pricing structure does not include the demand charge and super peak costs that exceed the actual cost of a kilowatt. Careful analysis, which factors in energy cost, environmental issues, metal loss and metal quality, should be performed before capital expenditures for new melting equipment take place.

3.5.1 Aluminum Furnace Energy Saving Concepts:

a. Minimize the time the furnace bath is uncovered either from charging or removing metal or dross.
b. Pre-heat charging material to significantly reduce the furnace energy input as aluminum melting temperature is significantly lower than iron. Many newer style furnaces contain scrap pre-heat chambers that capture waste heat.
c. Use clean scrap to reduce dross generation and addition of fluxes, which in turn reduces the amount of heat losses from slagging.
d. Upgrade older furnaces with new power supplies or burner systems to improve energy efficiency and with a quick payback.

3.6 Cupola Furnaces

The Cupola is a vertical shaft furnace that is either refractory lined or watercooled. It is equipped with a windbox that feeds combustion air into a charge mix of coke and scrap iron and steel. The cupola uses the most abundant source of energy in the United States, coal. The heat source for the cupola is supplied by metallurgical coke, which has an energy value of 14,500 Btu/lb. Coke is a very effective use of coal; only 13% of the total energy is lost in manufacturing coke compared to a 67% loss in burning coal for producing electricity. The cupola is potentially the least expense furnace for melting gray and ductile iron. Studies done prior to the recent energy crisis have shown cupolas to be in the range of 25% cost savings over Induction melting for high production applications. The total heat distribution of coke in a cupola has about 42% of the energy going into the metal and the remainder being lost to: a) creating Carbon Dioxide and Carbon Monoxide (CO); b) hot stack gases; and c) heat loss to the cupola shell. The majority of cupolas burn off the CO in the upper stack and many lose the potential energy that could be recovered.

The Cupola furnace was phased out of many foundries during the 1970's due to the cost of compliance to environmental regulations and the availability of electric induction melting equipment. For many smaller shops cupolas were not run on a continuous basis, leading to difficulty in producing a quality iron. The induction furnace solved this problem as well as requiring fewer environmental controls. Cupolas have maintained a foothold in the high production foundries because they are less costly to operate and they can use a lower quality scrap material as feedstock. But, they are still major users of electricity. A 50 ton per hour cupola will use about 1600 horsepower for the hot blast blower and dust collection fan.

3.6.1 Cupola Cost Saving Concepts:

a. Install a Recuperative Hot Blast system that utilizes the energy from burning CO to supply the heat for the hot blast air. Cupolas operate most efficiently when pre-heated air is used for combustion (900 °F to 1200°F).
b. Add Oxygen into blast air; most effective directly into the tuyeres and provides additional heat that can lower the amount of coke required.
c. Addition of coke fines directly into the tuyeres can also reduce the amount of coke added and can be used to control carbon levels.
d. With cold blast cupola the addition of a second row of tuyeres can reduce coke usage between 20% and 30%.
e. Use of the residual heat after the recuperative hot blast stage can be used to generate steam that has been used to generate electricity. A 75 ton per hour cupola can generate up to 3 Mega watts of power.
f. Minimize the charge door opening to reduce the size of dust collection required. An above the door takeoff cupola with a charge bucket design can use twice the cubic feet of air as a charge feeder design or a below the door takeoff design cupola.
g. In water cooled cupola, energy losses through the shell can be reduced with a refractory lining on the inside of the shell.

3.7 Ancillary Equipment:

The largest electrical consumption area besides melt operations is dust collection. In the survey results most ferrous operations reported having dry baghouses with up to 200 horsepower fans. Other large horsepower motors were on air compressor systems, equipment hydraulics and greensand sand systems. The size of the motors on this equipment will vary widely depending on the type of operations, but energy conservation concepts can be applied.

3.7.1 Energy Saving Concepts:

a. For larger motors that operate variable loads (fans & pumps), consider installation of Variable Frequency Drives controls. This will reduce voltage input to the motors if the load varies and reduce the energy consumed. A 20% reduction in speed can save 50% of the energy consumed.
b. On 100 horsepower and larger motors install reduced voltage starters to lower the demand peaks when turning equipment on.
c. Develop an Air Leak reporting system and repair all leaks in a timely manner. A 1/16" air leak requires 1 horsepower.
d. In the long term replace older reciprocating compressors with rotary screw compressors, which are about 20% more efficient.
e. Turn off Air Compressors when not needed. Install multiple compressors and consider zoning operations if operated at different times.
f. Operate Dust Collectors only with the associated equipment.
g. Turn off non-essential equipment when not in use.

4.0 Energy Providers and Energy Management:

Fundamental to developing energy cost reduction strategies is becoming knowledgeable of billing procedures, services and rate structures offered by your electric energy provider. Start with identifying the account manager for your energy provider. The energy provider's account manager can assist with setting up the most economical rate structure as well identify consulting services offered to energy clients. Services such as energy audits and trouble shooting electrical problems are frequently offered at low cost or free of charge.

4.1 Electricity Billing:

Electric bills may include the following basic charges:

- ***Consumption Charge***: Electric bills typically list the number of kWh used during the billing cycle followed by a rate, usually in cents per kWh as well as the consumption cost for the entire billing cycle. If time-of-use and seasonal rates apply, there may be a further breakdown of consumption costs by peak and off-peak hours where the cost per kWh varies according to summer and winter seasons as defined by the utility's time-of-use rate structure.

- ***Demand Charge***: The demand charge is a fee for the utility company's capital investment in equipment and transmission lines required to provide electricity to the end user. The charge is stated on the bill in maximum kilowatts or KVA per unit of time used during the billing cycle followed by the rate in dollars per kW and finally, the total monthly charge. Demand is usually measured every 15 minutes on the quarter hour and the monthly 15-minute maximum sets the final demand cost. The demand charge may be a combination of the monthly demand and/or a percentage of the maximum monthly demand for the previous 12 months effectively eliminating potential savings from plant shut downs or reduced production.

- ***Power Factor Penalties***: When a capacitive or inductive device is used on an AC circuit the current flowing through the circuit will be out of phase with voltage. A motor for example, is an inductive device and the current lags behind the voltage. Power factor is the ratio of actual power used in kW to the power used in kVA (kilovolts x amps). As with the electric motor, things that develop magnetic fields will decrease efficiency. This can result in a utility having to supply more current to the facility than is being used for useful energy (kW). A power factor cost on your bill is the way some utilities recoup their costs due to a reduction in efficiency caused by an inductive load such as a motor. If demand is billed by maximum KVA rather than kW, the power factor penalties are hidden and the customer pays the full penalty. Typically, utilities that bill in kW penalize their customers only if the power factor is less than 90%. Customers below the threshold may incur the power factor penalty or the utility may offer an option to pay a monthly power factor waiver fee instead of the power factor adjustment.

4.2 Negotiate the Right Rate Structure for Your Operation:

Making the effort to negotiate your billing rate structure can result in significant savings. For example, with plant data and an operations plan in hand, a northern California foundry was able to save an estimated $30,000 a month by switching from a Time-of-Use (TOU) billing rate structure to an Unbundled Time-of-Use UBTOU billing rate structure. This savings was achieved by working closely with the utility company and comparing actual plant operations and work schedules to the billing rate plans. Rate structure availability and details vary from utility to utility. Therefore, it is recommended that management work with their energy provider's account manager to find the most economical rate structure.

Briefly, typical rate plans offered by utilities include:

4.2.1 Time-of-Use (TOU) Rate Structure:

The energy charges vary by season and according to peak, super-peak and off-peak times of day. Due to the high energy and demand costs during normal business hours associated with the time-of-use rate structure, it may be beneficial for foundry managers to adjust their energy usage or demand to off-peak hours as shown in Figures 12 and 13. For example, using the summer TOU costs from Figure 13, Tables 11 and 12 demonstrate how total cost varies depending on the time of day that the foundry is run.

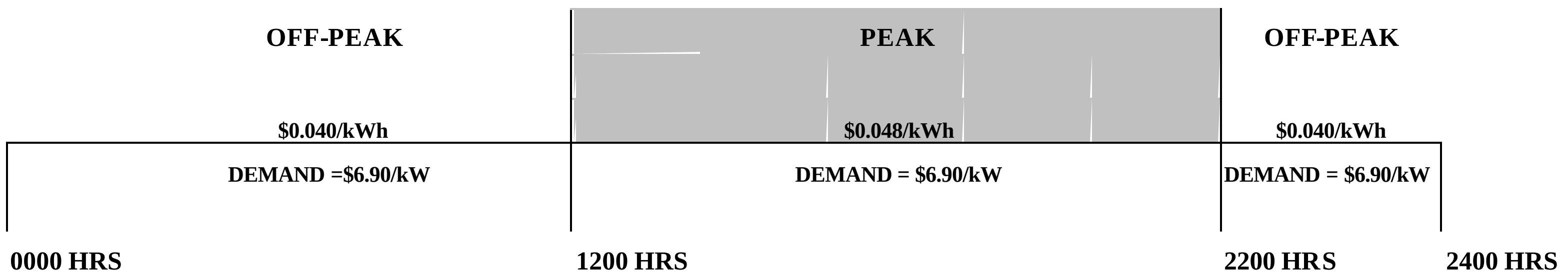
4.2.2. Unbundled Time-of-Use (UTOU Rate Structure):

This rate structure is more suitable for foundries preferring a more stable rate throughout the year, from season to season, who cannot alter usage in response to hourly or monthly price changes. This rate works best for foundries that use a minimal amount of energy during peak and super peak hours, or operate 24-hour or night shifts or weekends. The UTOU rate structure still uses variable energy costs throughout the off-peak, peak and super-peak times of day, but uses a smaller demand that remains uniform throughout the day (Table 13). With a uniform smaller demand charge throughout the day, foundries that fit the UTOU rate structure may accrue significant savings as shown in Tables 13 and 14 compared to TOU rates. Using the same foundry energy and demand meter data as in the TOU example (Table 11), the UTOU bill simulation shown in Table 14 accrues a significant savings of $19,223 as compared to the TOU-based costs shown in Table 12.

4.2.3. Interruptible Rate Structure:

Some utilities offer interruptible demand rate structures. To qualify for these rates, the foundry agrees to lower demand on short notice, usually during peak or super peak demand times of day. The disadvantage here is that furnaces have to be held or shut down resulting in a loss of productivity.

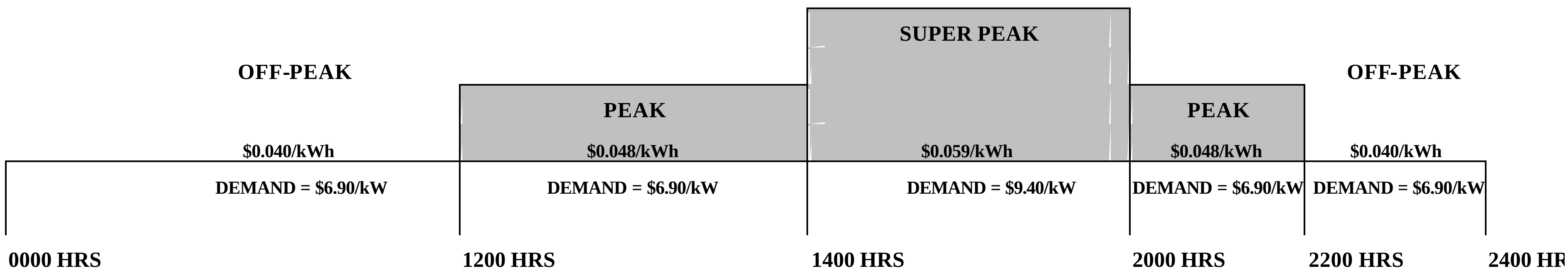
EXAMPLE WINTER SEASON TIME-OF-USE (TOU) RATE STRUCTURE
OCTOBER 1 THROUGH MAY 31



CHARGES	FEES
CUSTOMER CHARGE PER MONTH	**$ 85.00**
DEMAND CHARGE: $ per kW of max demand	**$ 6.90**
ENERGY CHARGE ($ per kWh):	
Peak Period	**$ 0.048**
Off-Peak Period	**$ 0.040**

Figure 12. Example Winter Season Time-of-Use (TOU) Rate Structure

EXAMPLE SUMMER TIME-OF-USE (TOU) RATE STRUCTURE
JUNE 1 THROUGH SEPTEMBER 30



CHARGES	FEES
CUSTOMER CHARGE PER MONTH	$ 85.00
MAX DEMAND CHARGE: $ per kW of max off-peak/peak demand	$ 6.90
MAX DEMAND CHARGE: $ per kW of max super-peak demand per month	$ 9.40
ENERGY CHARGE ($ per kWh):	
Super-Peak period	$ 0.059
Peak Period	$ 0.048
Off-Peak Period	$ 0.040

Figure 13 Example Summer Time-of-Use (TOU) Rate Structure

EXAMPLE MONTHLY ENERGY BILL BASED ON THE SUMMER TOU RATE STRUCTURE FROM FIGURE 13

Table 11: Simulated Monthly Meter Data with Energy Costs from Figure 13 Summer TOU Rate Structure

PERIOD	ENERGY kWh	ENERGY COST $/kWh	DEMAND kW	DEMAND COST $/kW
OFF-PEAK	17,518	$0.040	5,793 *	$6.90
PEAK	5,839	$0.048	3,216	$6.90
SUPER-PEAK	2,919	$0.059	1,685	$9.40

* Maximum demand that occurred during the month.

Table 12: Simulated Electric Bill Calculated from Summer TOU Rate Structure from Figure 13 and Table 11 Meter Data.

PERIOD	UNITS CONSUMED	UNIT COST	TOTAL COST
OFF-PEAK	17,518 kWh	$0.040	$700.72
PEAK	5,839 kWh	$0.048	$280.27
SUPER-PEAK	2,919 kWh	$0.059	$172.22
MAX DEMAND CHARGE	5,793 kW	$6.90	$39,971.70
CUSTOMER CHARGE		$85.00/Mo.	$85.00
		TOTAL:	$41,209.91

Note that demand charges form the major cost of this simulated electric bill. Note that the maximum demand (5,793kW) occurred during off-peak hours (Table 11) and the associated demand cost during this time period is $6.90/kW. Had the maximum demand occurred during super-peak hours the demand cost would have been $9.40 driving the final monthly cost even higher. By comparison, the energy costs ($0.040 to $0.059/kWh) are almost insignificant. Additional charges may be added to the bill such as county tax, state surcharge, and applicable power factor charges.

EXAMPLE: MONTHLY ENERGY BILL BASED ON AN UNBUNDLED TOU RATE STRUCTURE

Table 13: Simulated monthly Meter Data with Energy Costs Based on a Summer Unbundled TOU Rate Structure

PERIOD	ENERGY kWh *	ENERGY COST $/kWh	DEMAND kW *	DEMAND COST $/kW
OFF-PEAK	17,518	$0.0582	5,793 **	$1.87 ***
PEAK	5,839	$0.0792	3,216	$1.87***
SUPER-PEAK	2,919	$0.1287	1,685	$1.87***

* For comparison the same energy and demand meter data is used from the TOU bill simulation in Table 11. The energy and demand costs are from an UTOU rate structure.

** Maximum demand that occurred during the month.

*** Note that the UTOU demand cost is lower and uniform throughout the day as compared to the TOU rate structure.

Table 14: Simulated Electric Bill Calculated from Summer Unbundled TOU Rate Structure and Table 13 Meter Data.

PERIOD	UNITS CONSUMED	UNIT COST	TOTAL COST
OFF-PEAK	17,518 kWh	$0.0582	$10,195.48
PEAK	5,839 kWh	$0.0792	$462.45
SUPER-PEAK	2,919 kWh	$0.1287	$375.68
MAX DEMAND CHARGE	5,793 kW	$1.87	$10,832.91
CUSTOMER CHARGE		$120.00/Mo.	$120.00
		TOTAL:	$21,986.52

Using the same foundry energy and demand data from Table 11, the simulated UTOU bill (Table 14) achieves a cost savings of:

TOU monthly cost (Table 12)	$41,209.91
UTOU monthly cost (Table 14)	- $21,986.52
	$19,223.39

As with the TOU rate structure, additional charges may be added to the bill such as county tax, state surcharge and applicable power factor charges.

4.3 Establish an Energy Management Program:

To set realistic energy use and cost management goals, the best place to start is with the details of your current energy use, a current inventory of plant equipment, and performing an energy audit. While not foundry specific, an excellent source of general energy conservation information applicable to most facilities is the "Greening Government Facilities" web site at http://www.eren.doe.gov/femp/greenfed/index.html. This is the Federal Energy Management Program (FEMP) and has guidelines for improving the energy efficiency of federal facilities covering HVAC, boiler, air conditioning, chillers, high efficiency motors, variable frequency motor drives, lighting guidelines, water conservation, building design, landscaping, and more.

4.4 Establish a Baseline Inventory of Plant Equipment:

To improve any system, it is necessary to determine where you are and where you want to go. If it has not already been done, begin with an inventory of plant electrical equipment:

- Catalog electrical equipment in terms of age, condition, and power requirements.
- Catalog, update, and organize electrical as-built drawings.
- Update equipment labels.

4.5 Establish a Plant Wide Energy Baseline with an Energy Audit:

The primary reason for an energy audit is to better understand your energy use and performance and to give management an energy use profile with enough detail to develop overall cost control strategies. In short, the energy audit illustrates how the energy purchased is used in the foundry process. Comparing the energy input with foundry output helps identify priorities for efficiency and load management. For example, an audit will help identify the top energy users and the areas for possible efficiency improvements allowing management to focus on the most cost effective opportunities. An energy audit should provide the following plant energy data:

- Present total monthly energy costs by type (electricity/natural gas).
- Cost per unit of energy by type and time of year.
- Energy consumption of each major energy-using unit (furnace, air compressor, molding, sand-mixing equipment, etc.).
- Energy consumption of each production process.
- Establish a hourly energy demand profile, hour by hour.
- Lighting, power and space heating costs.

4.6 Getting Started:

Start with your equipment inventory and energy bills, and verify the largest users and loads they serve. To obtain historical data, your energy provider may be able to provide billing records for the past months or even years. If you do not have the in-house expertise to conduct an energy audit, contact your energy provider who may be able to perform the audit for a fee or possibly at no cost. If your energy provider does not offer an energy auditing service you can hire a consultant to perform and interpret an energy audit for you.

4.7 Identify Analytical Services Available from Your Energy Provider:

Most utilities provide diagnostic and customer support services. These services may include diagnostics, energy audits, and energy monitoring equipment and software. If power quality problems in your plant are suspected some utilities will set up diagnostic equipment in your plant and provide a report free of charge. These reports may uncover power quality, line noise, voltage fluctuations or power factor problems. Additionally, serious safety issues such as improper grounding may be revealed. A typical power analysis report may include the following:

- ***Initial Power Conditions Section***: This section documents measurements taken by phase, neutral, and ground and may reveal problems such as improper grounding.

- ***Event Section***: This section summarizes voltage events that occur during the monitoring interval. Events are defined as changes in the monitored voltage. These changes may be subtle or severe. A power tolerance curve provides a graphical representation of the likelihood of an event to disrupt equipment.

- ***Voltage Current and Frequency (VIC) Section***: This section contains summaries for voltage, current, and frequency parameters during the monitoring period.

- ***Power Section***: This section contains the VA, VARS, Watts, and power factor acquired during the monitor interval. For multiphase locations, voltage and current imbalance are also included.

- ***Harmonics Section***: This section contains the voltage and current harmonic and harmonic distortion summaries acquired during the monitor interval.

4.8 Industrial Assessment Centers (IAC):

Under the auspices of the U.S. Department of Energy Office of Industrial Technology (OIT), the IAC program allows eligible manufacturers to have comprehensive energy assessments performed at no cost. Teams of engineering faculty and students from the IAC centers, located at 26 Universities around the country, provide the assessment services. The IAC teams conduct energy audits and provide recommendations to manufacturers to identify opportunities for energy efficiency improvements, waste minimization and productivity improvement. The university-based IAC team starts with a written survey followed by a one or two day site visit taking engineering measurements that form the basis for later energy savings recommendations. From the written survey and engineering measurements, the IAC team performs a detailed analysis for recommendations with related estimates of costs, performance, and payback times. Within 60 days of the site visit, a confidential report, detailing the findings and recommendations of the IAC team, is sent to the host plant.

4.8.1 IAC Assessment Eligibility:

To be eligible for an IAC energy assessment the foundry must meet the following criteria:

- Within Standard Industrial Codes (SIC) 20-39.
- Within 150 miles of a host campus.
- Gross annual sales less than $100 million.
- Fewer than 500 employees at the plant site.
- Annual energy bills more than $100,000 and less than $2 million.
- No professional in-house staff to perform the energy assessment.

4.8.2 OIT and California IAC Host Universities Points of Contact:

For additional information contact:

- **Office of Industrial Technology Resource Center**
  Mail Stop EE-24
  U.S. Department of Energy
  1000 Independence Avenue, SW
  Washington, DC 20585
  (202) 586-2090

- **San Diego State University (IAC participating California University)**
  Dr. Asfaw Beyene
  (619) 594-6207
  abeyene@rohan.sdsu.edu

- **San Francisco State University (IAC participating California University)**
  Dr. Ahmad Ganji
  (415) 338-7736
  aganji@sfsu.edu

- **Loyola Marymount University**
  Dr. Bohdan W. Oppenheim
  310-338-2825
  bopphe@lmu.edu

- IAC Program Information can be found at www.oit.doe.gov/iac click on Industrial Assessment Centers

4.9. Energy Monitoring and Management Systems:

To be a well-informed energy consumer, foundry managers need to know how much energy the plant consumes. Management needs to know how much power is used, what the major loads are, how often electric power is used, and how much the power costs. Providing this information ranges from installing an energy monitoring system that provides basic consumption and billing verification to energy management systems that control melt furnace electrical loads to achieve optimum energy use.

4.9.1. Overview:

Service entry metering and power quality equipment installed at key points throughout the plant form the most basic energy management approach. Going up a notch by connecting the basic metering equipment with a PC loaded with energy monitoring software can provide real-time consumption and cost data useful for managing foundry production schedules, billing verification and rate negotiation. Taking another step up, more sophisticated energy management systems interconnected with melt equipment and utility metering equipment can minimize energy costs by cycling furnace power settings following software controlled load profiles and billing algorithms. However, energy management systems can be expensive and may require hiring extra staff to run the systems. Also, an energy audit may reveal many low cost "low hanging fruit" type improvements in facilities and operations procedures that should be explored first. Therefore, it is recommended that foundry management conduct an energy audit, implement improvements gleaned from the audit and make full use of basic metering equipment before deciding to install a more sophisticated energy monitoring or management system.

4.9.2 Energy Monitoring Systems:

Most of these PC based systems provide real-time continuous on-line tracking from the electrical meter that show how energy is being used along with associated costs. The monitoring system usually consists of a phone line, modem, PC, meter interface and software to capture and display energy consumption data. The software can generate bills and load profiles on an hourly, daily, or weekly basis. With easy to use Windows ® application software and graphical displays, many energy monitoring systems allow forecasting the potential cost savings of switching from one rate to another, moving on-peak workload to off-peak periods and electric bill verification. Key energy monitoring software attributes allow users to:

- Determine actual energy consumption in real-time.
- Determine when energy consumption exceeds targets
- Review daily energy cost graphs and load profiles to improve energy management.
- Efficiently plan use and provide data for negotiating lower energy prices through daily and monthly demand analysis.
- Reschedule load demand times to avoid peak demand costs.

4.9.3 Energy Management Systems:

In addition to providing energy load profiles, energy management systems control plant equipment via hard-wired connections to avoid high-energy costs. For example, using a demand management system that reduces costs through the automatic control of melt furnace power can reduce operating costs. Power consumption of the melt furnace is monitored by transducers mounted on the furnace power supply. In turn, the transducers are interfaced to the energy management system and the load on the furnace is controlled by changing the operator set points by adjusting potentiometer load control settings. The amount of control is calculated by comparing the utility metering input information with the plant's desired demand limit set point. In this example, the system continuously collects electrical information from the main utility meter and the transducers mounted on the melt furnace power panel. The energy management software monitors the energy being used and forecasts the foundry's demand in accordance with the billing algorithm used by plant management. By comparing the forecast demand with the desired set point demand, the energy management system issues control command outputs to raise or lower melt furnace loads. With this type of energy management system, foundry managers are provided with a real-time graph of furnace load versus. time with the target set point displayed. Additionally, the energy management software provides analytical tools for historical and cost analysis.

4.9.4 Energy Monitoring and Management Systems Points of Contact:

The following list is included as a starting point for anyone wanting to contact potential vendors of energy monitoring/management systems: They were selected from a list of over 50 vendors. No endorsement is intended.

- **Optimize IT**
  ABB Automation Inc.
  Jose Mundassery
  1460 Livingston Avenue
  P.O. Box 6005
  North Brunswick, NJ 08902
  Phone: 732-932-6400
  Fax: 732-828-7272
  www.abb.com/usa/meltpro Jose.mudassery@us.abb.com

- **E2MS Real Time Energy Management Software**
  E2MS Inc.
  3-12 Stanley Court
  Whitby, Onterio, Canada
  L1N 8P9
  Phone: 800-565-3226
  Fax: 905-430-3226
  www.e2ms.com info@e2ms.com

- **Energy Watchdog**
  UtiliVision
  200 Innovation Blvd., Suite 252
  State College, PA 16803
  814-689-1048
  www.energywatchdog.com/index

- **EnerLink**
  EnerLink, A Division of SCT
  3500 Parkway Lane NW, Suite 650
  Norcross, Georgia 30092
  Phone: 800-528-3220
  www.enerlink.com info@enerlink.com

- **Beacon**
  Oarsman Corporation
  Randy Davis
  606 Kampmann Blvd.
  San Antonio, TX 78201
  Phone: 210-735-5580
  www.oarsman.com/site/contact.asp rdavis@oarsman.com

5.0 Conclusions and Recommendations

The information received in the Metal Melting Survey gave a profile of California metal melting operations that were segmented into two groups, Ferrous and Non-Ferrous. There is a large variation in the type of castings produced at the facilities responding to the survey. The three largest tonnage operations in California produce approximately 50% of the total tonnage. The remaining 200+ foundries represent smaller operations that have limited technical resources and most need the suggestions presented in this report.

Below is other basic energy usage information:

1. The large operations, both in Ferrous and Non-Ferrous, did not melt with electricity but depended on fossil fuel energy.
2. There are only 4 Cupola operations, but they represent 70% of the Ferrous and 45% of the total tonnage reported in the survey.
3. The remaining Ferrous operations where using Induction Melting furnaces.
4. The Aluminum smelters were using gas furnaces, but the foundries and die casters had a mix of electric and gas furnaces.
5. The average cost for Electricity for all reporting operations is $0.074 per kWh.
6. Most operations are reacting to the energy crisis through energy conservation measures and changes in operating schedules.

Energy usage and cost saving strategies are reviewed in the body of the report but come down to these basic concepts:

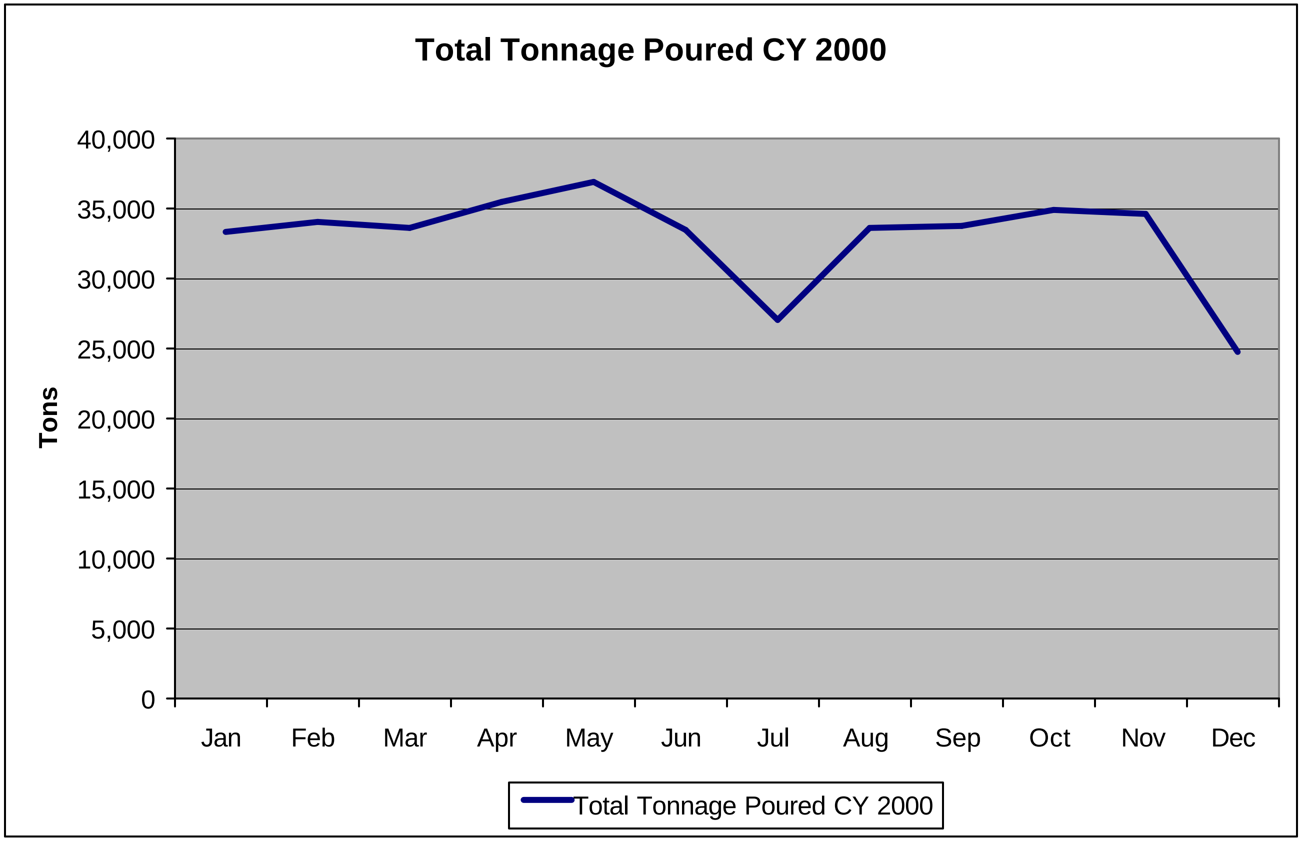
1. Minimize the time any furnace bath is exposed to reduce radiation losses.
2. Reduce Slag and Dross generation by charging the furnace with clean scarp and returns.
3. In electric melting consider Pre-Heating of scrap to reduce electrical input. This can be from fossil fuel, but the use of waste heat would be optimum.
4. Maximize the Power on time in a furnace for melting and minimize holding time.
5. Upgrade older furnaces: a) newer design Aluminum Gas furnaces that capture waste heat and use it to pre-heat charge materials; and b) replace older induction power supplies, new power supplies and new designs can melt quicker with the same energy input.
6. On larger motors add variable Frequency Drives to reduce voltage when the load drops and conserve energy.

Energy Management suggestions discussed in this report:

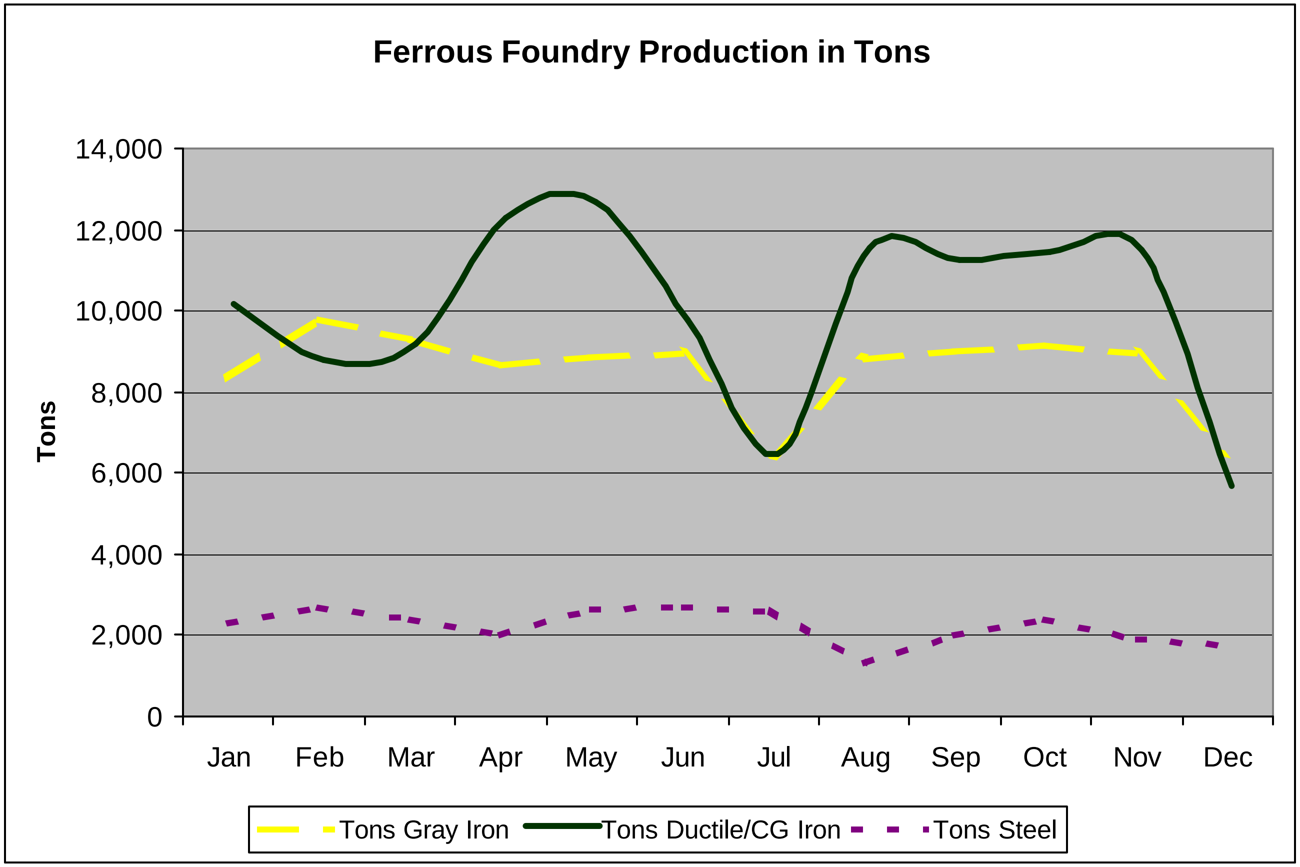
1. Understand your Electric Billing rates and the rate options available.
2. Establish a baseline Energy usage for your facility and inventory the energy consuming equipment.

3. Perform a plant wide Energy Audit to determine energy consumption by area and by time of day.
4. Consider Installation of an Energy Monitoring System.
5. Turn off non-essential equipment when not needed.
6. If possible, move workloads to lower cost off-peak billing times of day.

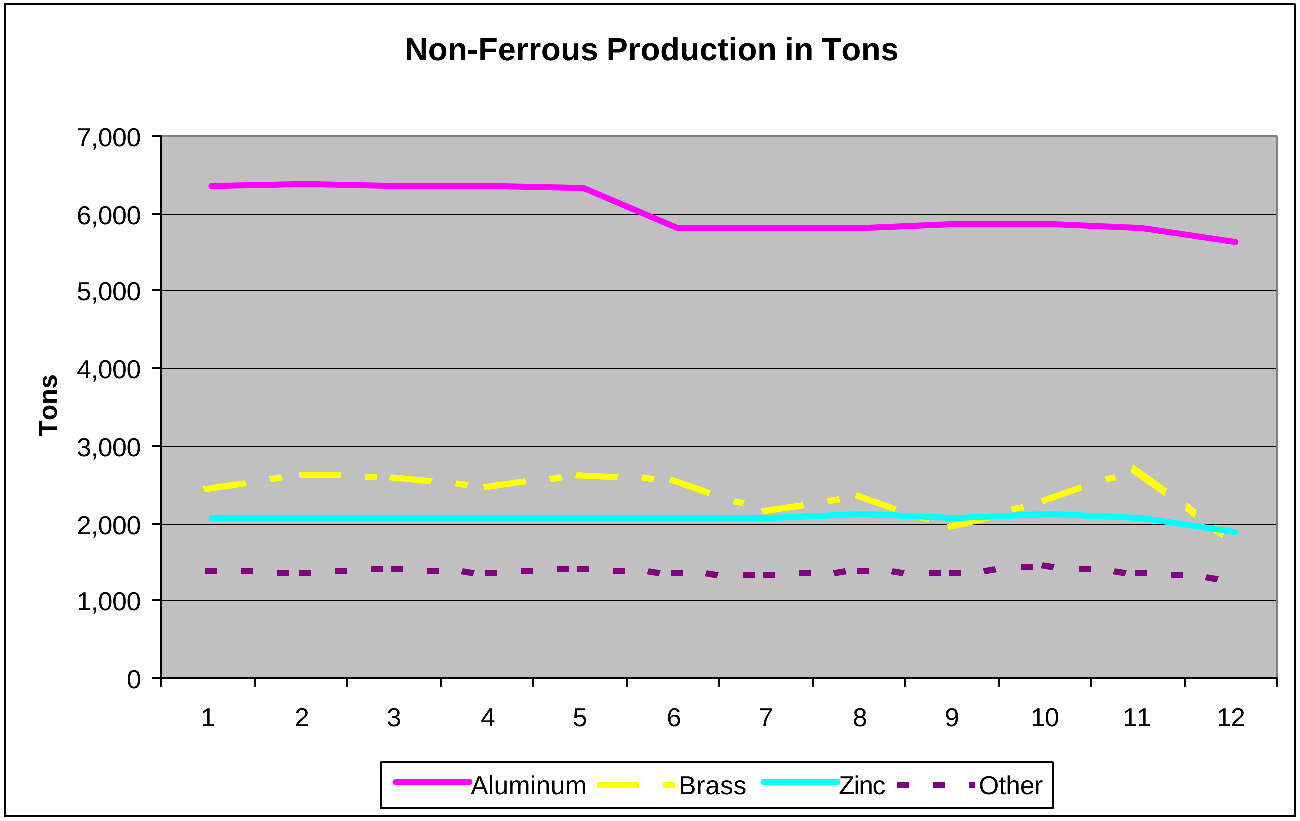
Appendices – Charts of Survey Results



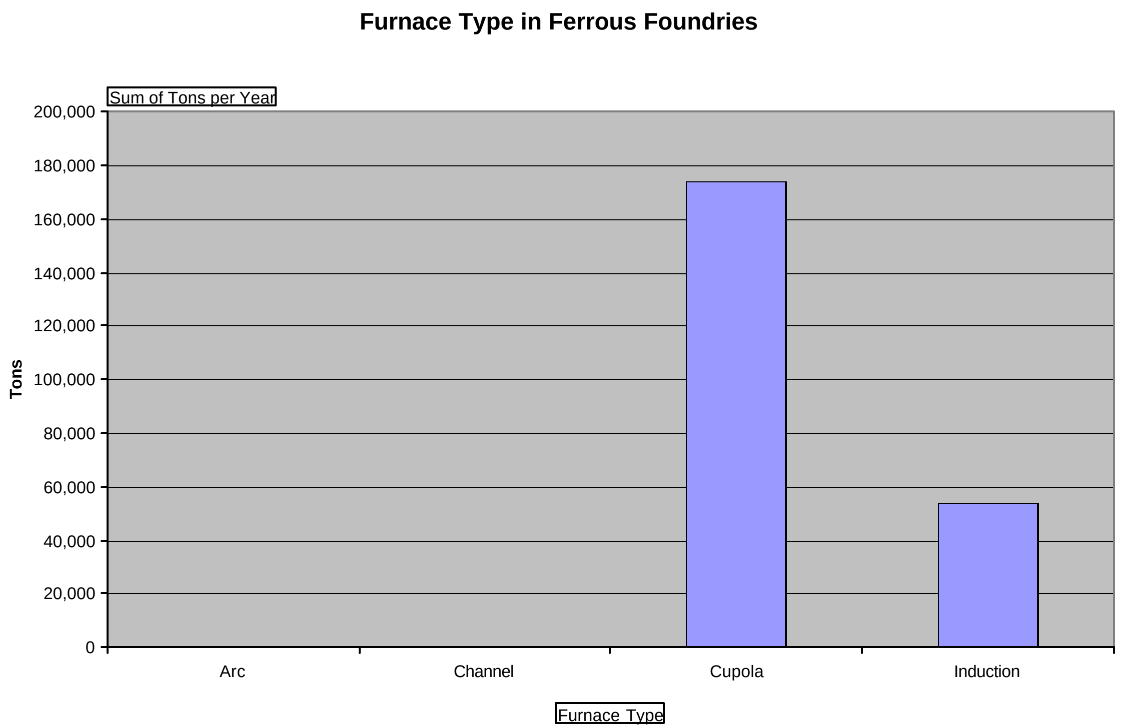
Appendix 1. Total Tonnage Poured CY 2000



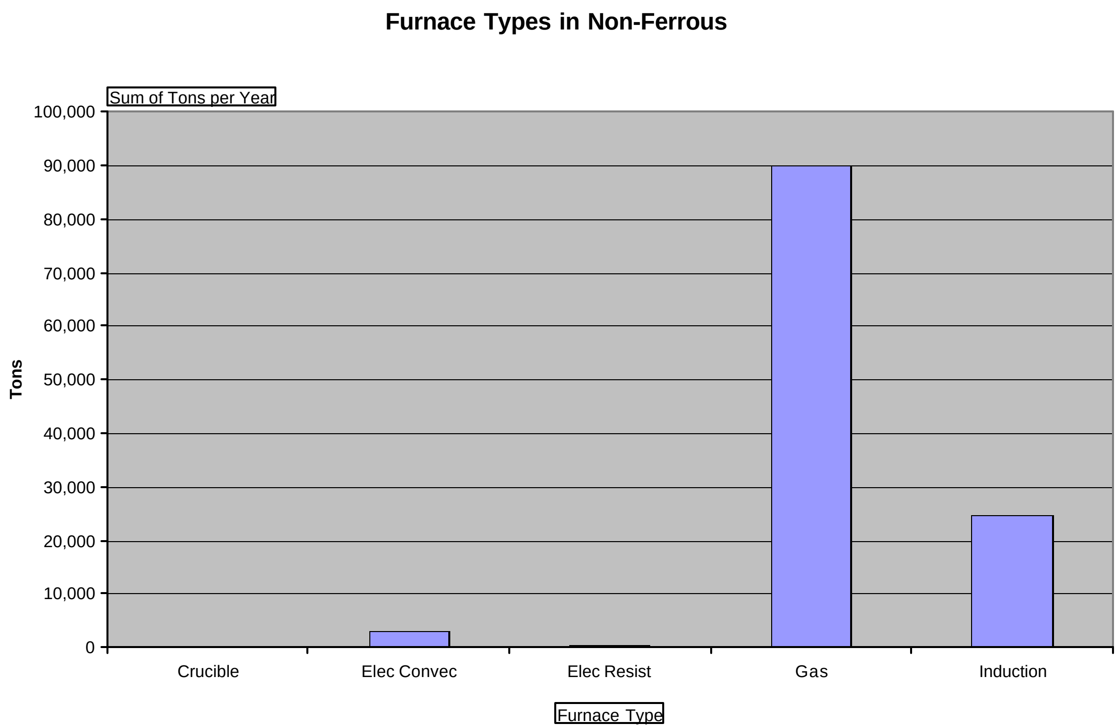
Appendix 2. Ferrous Foundry Production in Tons



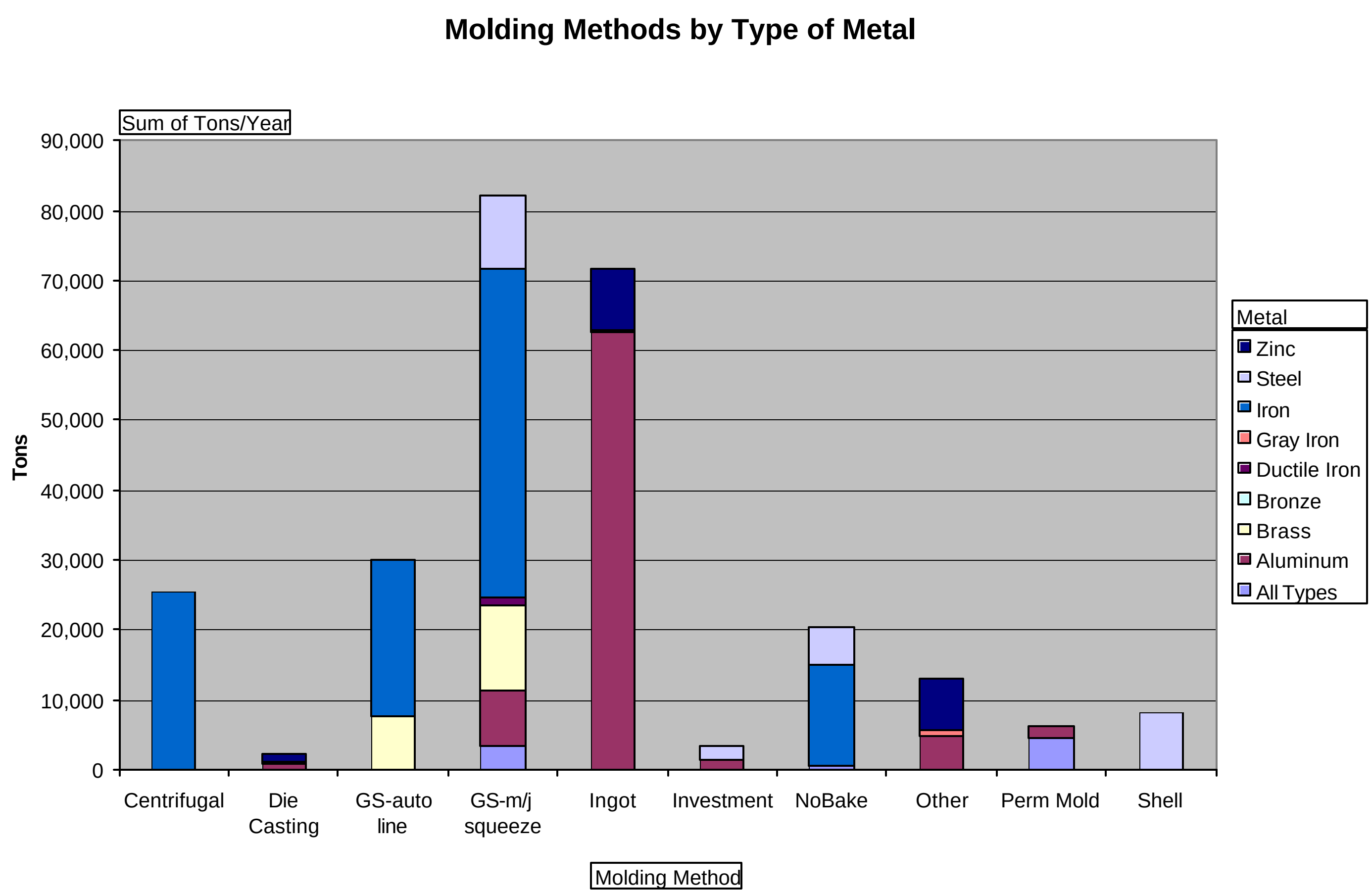
Appendix 3. Non-Ferrous Production in Tons



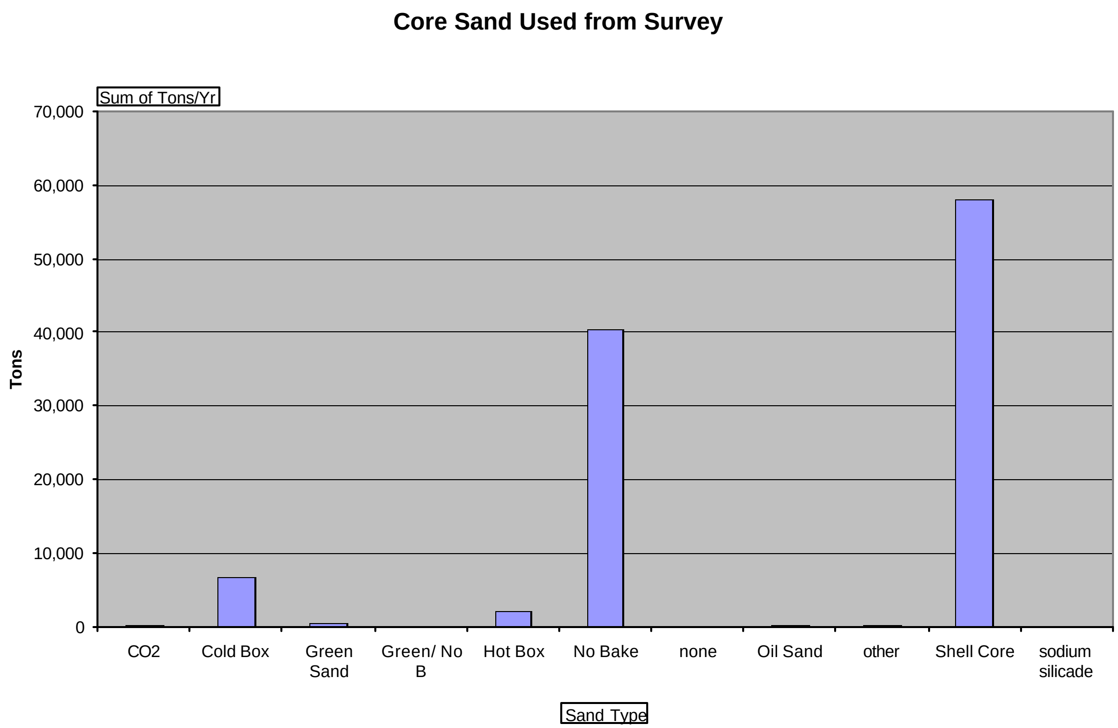
Appendix 4. Furnace Types in Ferrous Foundries



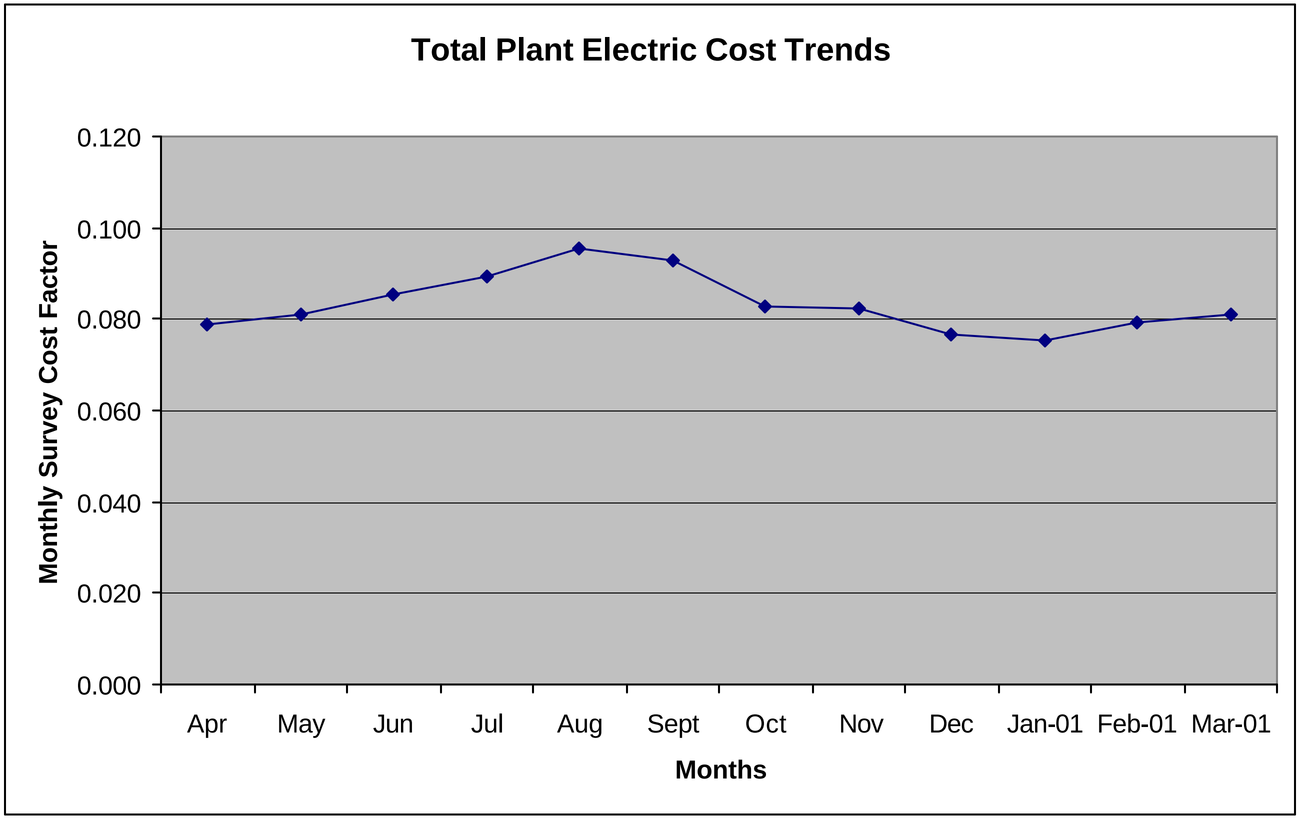
Appendix 5. Furnace Types in Non-Ferrous Foundries



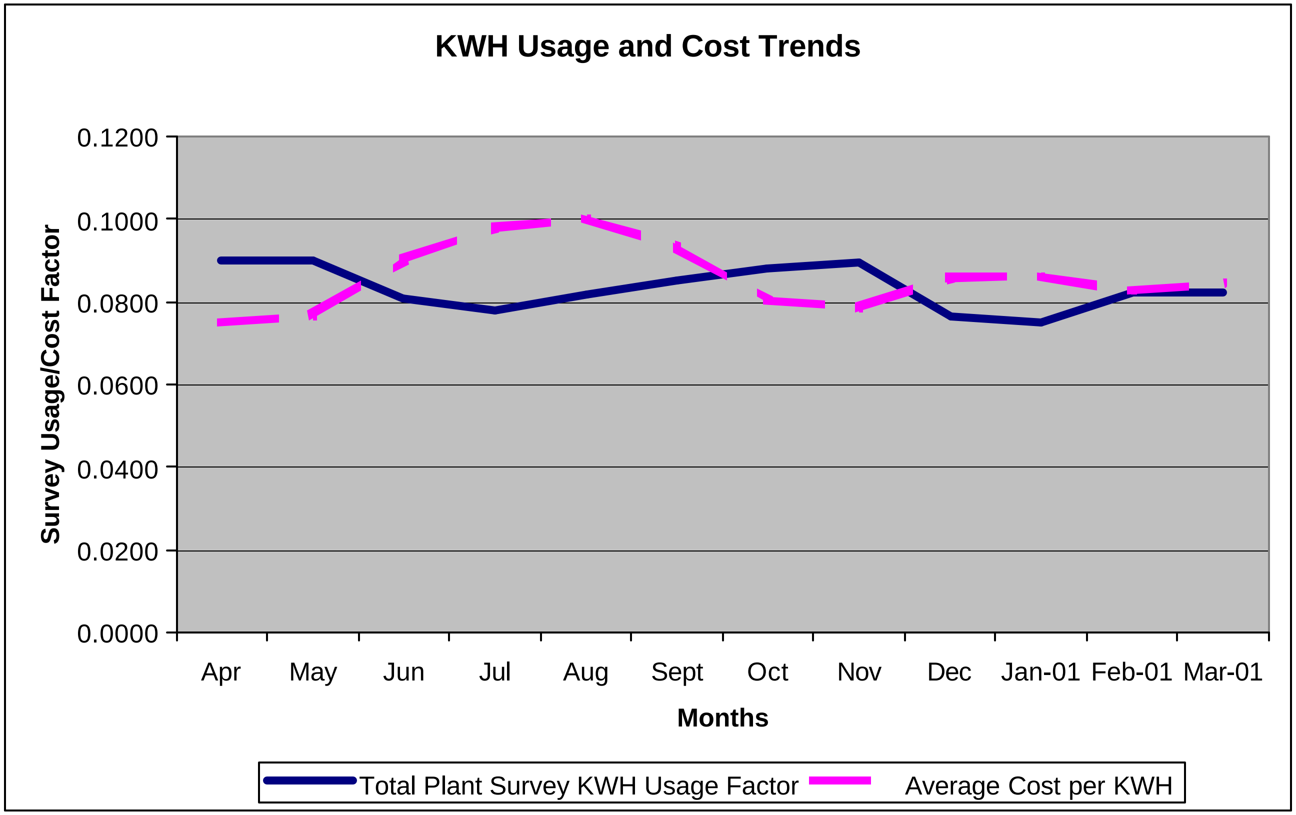
Appendix 6. Molding Methods



Appendix 7. Core Systems Used in Foundries (based on core sand tonnage)



Appendix 8. Total Plant Electric Cost



Appendix 9. KWH Usage and Cost Trends

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total Tons Gray Iron	8,346	9,832	9,301	8,679	8,861	8,953	6,392	8,809	8,998	9,153	8,959	6,454	102,734
No of Locations	13	13	13	13	13	13	13	13	13	13	13	13	13
Average per location	642	756	715	668	682	689	492	678	692	704	689	496	7,903
Percent of Total Tonnage													**26%**
Total Tons Ductile/CG Iron	10,129	8,744	9,123	12,219	12,623	9,722	6,400	11,490	11,196	11,377	11,437	5,621	120,080
No of Locations	11	11	11	11	11	11	11	11	11	11	11	11	11
Average per location	921	795	829	1,111	1,148	884	582	1,045	1,018	1,034	1,040	511	10,916
Percent of Total Tonnage													**31%**
Total Tons Steel	2,315	2,711	2,423	2,009	2,658	2,706	2,590	1,325	2,036	2,395	1,929	1,776	26,872
No of Locations	11	11	11	11	11	11	11	11	11	11	11	11	11
Average per location	210	246	220	183	242	246	235	120	185	218	175	161	2,443
Percent of Total Tonnage													**7%**
Total Tons Aluminum	6,324	6,344	6,321	6,324	6,307	5,798	5,775	5,792	5,841	5,845	5,775	5,612	72,059
No of Locations	23	23	23	23	23	23	23	23	23	23	23	23	23
Average per location	275	276	275	275	274	252	251	252	254	254	251	244	3,133
Percent of Total Tonnage													**18%**
Total Tons Brass	2,456	2,627	2,614	2,480	2,635	2,583	2,158	2,388	1,968	2,305	2,703	1,764	28,683
No of Locations	11	11	11	11	11	11	11	11	11	11	11	11	11
Average per location	223	239	238	225	240	235	196	217	179	210	246	160	2,608
Percent of Total Tonnage													**7%**
Total Tons Zinc	2,052	2,052	2,052	2,052	2,052	2,052	2,052	2,102	2,052	2,102	2,052	1,852	24,524
No of Locations	4	4	4	4	4	4	4	4	4	4	4	4	4
Average per location	513	513	513	513	513	513	513	526	513	526	513	463	6,131
Percent of Total Tonnage													**6%**
Total Tons Other	1,399	1,376	1,425	1,378	1,428	1,361	1,346	1,392	1,361	1,462	1,363	1,304	16,594
Percent of Total Tonnage													**4%**
Total All metals	**33,021**	**33,686**	**33,260**	**35,141**	**36,564**	**33,176**	**26,713**	**33,297**	**33,451**	**34,638**	**34,219**	**24,382**	**391,547**

Appendix 10: Type of Metal and Tonnage Poured